#INT-88361-COA
"Erosion of Fine Sediment from Disturbed and Natural Batholith Watersheds: An Attempt to Identify Source Areas of Stream-Sediment Load Using Magnetic Properties"
BOISE STATE UNIVERSITY
FS Contact: John King
CoOp Contact: Dr. Spencer H. Wood

Final Report INT-88361

Magnetic Properties of Soil Profiles and Fine Stream Sediment Derived from Granitic Rocks of the Idaho Batholith: An attempt to identify sources of suspended stream-sediment in watersheds disturbed by timber harvesting.

June 16, 1994

Final Report to the U.S. Forest Service, Intermountain Research Station, Ogden, Utah for the BSU-USFS Cooperative Research Agreement of 1989.

Spencer H. Wood*
Department of Geosciences
Boise State University
Boise, Idaho 83725

*at Department of Geological Sciences,
Chiang Mai University, Chiang Mai 50002, Thailand
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Steve P. Lund
Department of Geological Sciences
University of Southern California
University Park
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ABSTRACT

Vertical profiles of young soil and colluvial deposits in mountain watersheds of the Idaho batholith (elevation ≈ 2000 meters) show an accumulation of magnetic mineral material in the upper one meter of topsoil developed or accumulated upon weathered granodiorite. Samples were gently disaggregated and the fine fraction separated from the coarse fraction by settling the sand fraction for 1.5 minutes in water. Magnetic properties were measured on the suspended material that settled over a two-week time (mostly fine sand and silt) in order to simulate sources of suspended stream sediment. Rock-magnetic properties measured on the fine fraction are: low-field magnetic susceptibility (CHI), anhysteretic remanent magnetism (ARM), saturation and partial saturation remanent magnetism (SIRM and pSIRM) - all showing a 5 to 10 fold increase in the upper 1.0 meter in contrast to the underlying weathered granodiorite (gruss), bedrock, and colluvium. Magnetic susceptibility values (CHI/mass) for 20 samples of topsoil average 5.6 ± 2.8 (1σ) and for 12 samples of gruss, bedrock, and colluvium deeper than 1.0 meter the values average 0.8 ± 0.5 (1σ) [SI units]. It is likely, but as yet unproven, that authigenic maghemite is forming in these young soils by pedogenic processes.

The above magnetic signature of the topsoil versus the underlying bedrock and colluvium may have application to identifying the source of suspended sediment derived from watersheds disturbed by road construction and timber harvesting in comparison to undisturbed natural watersheds in the coniferous forest zone. To test this idea, turbid stream water samples were taken in 25-liter buckets from 6 different small watersheds (≤2km^2) during the peak snowmelt runoff in April 1989. Suspended sediment loads were 20 to 100 mg/liter. Values of CHI/mass for 16 different samples averaged 3.4 ± 1.8 (1σ) and ranged from 1.6 to 8.6 [SI units]. A crude calculation assuming that sediment sources of topsoil of 5.6 are diluted with weathered-bedrock sources of 0.8 to give an average suspended sediment value in streams of 3.4, suggests that on the average, suspended sediment stream derives 65% mass from topsoil (< 1 meter depth), and 35% mass from the subsoil weathered granodiorite (> 1-meter depth).

We did not detect a significant difference in magnetic signature of suspended sediment from the 6 watersheds sampled, some of which had been disturbed by logging and road construction a few years prior to 1989. We wish

to point out, however, that only 1 to 3 samples were taken in April 1989 from each watershed - and that systematic sampling over time from watersheds may be able to detect differences immediately after disruption of soils or during unusual moisture conditions leading to deep-seated slope failures which would, in theory, produce more sediment load from below the topsoil.

INTRODUCTION

This is a preliminary study of magnetic properties of fine particles in soils and suspended sediment derived from granodiorite of the Idaho batholith. We investigated the feasibility of using magnetic properties to identify where in the profile of weathered granitic rock most of the suspended load of streams is derived. Motivation for the study is the need to identify the principal sources of suspended sediment in streams, particularly those sources in areas disturbed by timber harvesting and road building. Severe erosion of disturbed areas of steep slopes in the central Idaho mountains has produced high sediment loads in some streams. Deposition of the suspended load of silt sediment has severely damaged the gravel-bed spawning habitat of native trout and endangered runs of anadromous salmon in some streams of central Idaho (Platts, 1970; Seyedbagheri and others, 1987).

Bedrock of the Silver Creek Experimental Forest (Figure 1) is reported to be muscovite-biotite granodiorite, the lithology of the core rocks of the Atlanta lobe of the Idaho batholith (Fisher et al, 1983; Johnson et al, 1988). In the areas we examined biotite granodiorite was the dominant rock, muscovite being generally absent. Also present in the area are rare dikes of felsite porphyry of early Eocene age. The steep slopes consist of bedrock outcrops, areas of gruss, and accumulations of sandy colluvial soil deposits derived from the granitic rocks. Vegetation is a mixed coniferous forest of ponderosa pine, Douglas fir, Englemann spruce, and an understory of small trees and shrubs. Elevation of watersheds is from 2073 m (6800 ft) to 1370 m (4500 ft). Individual watersheds of the study area are typically 1 to 2 km^2 (0.4 to 0.8 mi^2. These watersheds are all tributaries of Silver Creek, the main throughgoing stream of this mountain valley. The principal streams that drain the watersheds are typically 2.4 km (1.5 mi) long. Slopes are typically 15 to 30 degrees, generally facing southeast.

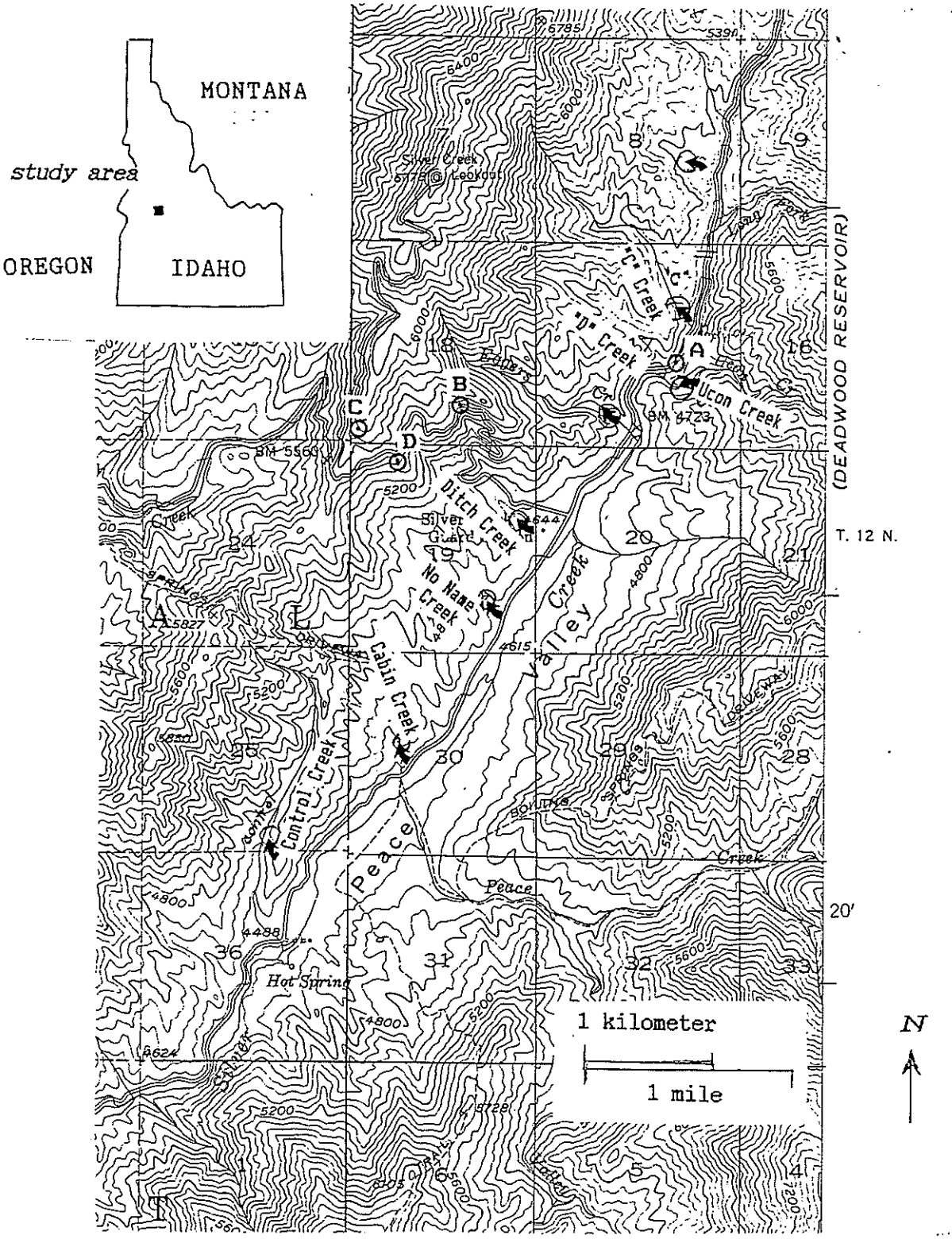


Figure 1. Location map of the Silver Creek study area. Coordinates of map center are about 44°25'N lat, 115°45'W long. Locations of soil profiles are shown with a circled dot labelled A,B,C, or D. Locations of points where turbid stream waters were sampled are shown with an arrow. Creeks sampled are Control Creek, No Name Creek, Eggers Creek, Ditch Creek, "D" Creek, "C" Creek, and Ucon Creek. Cabin Creek samples were destroyed by vandals.

Annual precipitation on the study area averages about 890 mm(35 inches) with most occurring during winter months. Winter temperatures in some years range down to -35°C (-30°F) for several weeks. Summer temperatures in some years range up to 32°C (90°F) at mid-day. Summers are hot and dry with occasional, localized convective storms. More generalized frontal type rains are common in May and June and in the fall in late September and October. About 65% of the annual precipitation occurs as snowfall that produces an average snowpack water equivalent of about 550 mm (22 inches) - although the snowpack can be quite variable from year to year (Megahan and others, 1991).

This study was originally designed to examine for magnetic property-signatures in the suspended sediment from drainages which had been disturbed from their natural state by several methods of timber harvesting and logging road construction. The method of watershed disturbance is tabulated in Table 1.

TABLE 1. Methods of timber harvesting and road construction in drainages of the Silver Creek Study area (Figure 1).

drainage name	method of logging and road construction
Control Creek	3 large clear cuts in 1976, no roads, burned
Cabin Creek	Roads constructed to high standard, tractor hauled, select and clearcut.
No Name Creek	not known
Ditch Creek	Roads constructed to a low standard small clearcuts.
Eggers Creek	no disturbance, control watershed
"D" Creek	Helicopter logging, no roads, large clearcuts.
"C" Creek	Helicopter logging, no roads, small patch cuts.
Ucol Creek	No disturbance, natural watershed.

Four soil profiles were sampled for magnetic properties, and the results are shown in Figures 2a, 2b, 2c, and 2d. These results are the most interesting because they show that magnetic material accumulates in the upper one meter of all of the soil profiles - as will be discussed later in this report.

SAMPLING METHODS

This study originally intended to study only the suspended sediment obtained on filter paper samples from Manning samplers - which take a time sequence of samples from stream water. Because the Manning samplers produced such small samples (a few hundredths of a gram or less), we elected to take a 25 liter (6 gallon) plastic bucket sample of the stream water at a time when the stream was at a high stage, and turbid with suspended sediment during the spring snowmelt flood on March 18 and 19, 1989. Into the bucket of water we placed a few drops of $CuSO_4$ solution to prevent algal growth, and then sealed the bucket with a plastic lid. The samples were allowed to settle until June 24, at which time the clear water was decanted, and the settled sediment was later dried in a microwave oven. Colloidal clay and some fine organic material did not settle and was thrown out with the water, and therefore removed. These bucket samples yielded between 0.7 and 4.0 grams of sediment per 25 liter bucket of water, and 1.5 grams/25 liters was a typical value. The dry samples were packed into square plastic boxes, and then packed with rock salt (a non-magnetic filler) to fill the void space in the container. These samples were sent to the University of Southern California (USC) rock-magnetism laboratory for determination of magnetic properties.

Only a few of the filter-paper samples of sediment from the Manning samplers were marked by laboratory technicians in 1989, so without location and time, we elected to run only the 14 of the samples that were marked. Because of small sample size only ARM (anhysteritic remnant magnetism) was determined in 1990 - it was not possible to determined susceptibility. In 1992 the samples were re-analyzed for IRM (isothermal remanent magnetism), when that instrumentation became available at USC. Values for ARM and IRM are quite similar for suspended sediment from the three drainages sampled: Control Creek, Eggers Creek, and "C" Creek. The values of magnetic properties of suspended sediment from the several creeks varied somewhat, but were not

consistently different.

In subsequent years (1990 - 93) the suspended sediment concentrations were reportedly low on account of low snowpack - so we did not pursue obtaining other samples from the Manning automatic samplers or additional large bucket samples.

It was decided to examine profiles of the soil and weathered granite in order to see if they differed and could be matched to the magnetic property signature of creek sediment. Description of profiles is in Figures 3a, 3b, 3c, and 3d. Excavation and sampling of soil pits and road cuts was done on March 6, 1990 (profile A) and September 9, 1991 (profiles B, C, AND D). Samples were collected by digging a soil pit or scraping a road cut clean with a shovel, and then cleaning the exposure of soil in contact with the steel shovel with a plastic trowel and brush - in order assure no magnetic influence of the sampling on the samples. Soil samples from the clean face were placed in 0.5 liter plastic bags.

To separate the potential suspended load from sand and coarser particles of the soil profile samples, each sample was placed in a 25 liter bucket and mixed and agitated with tap water. The coarse particles were allowed to settle for one minute. The remaining suspension was decanted into a clean bucket and allowed to settle for one week. The clarified water was then poured off, and the silty sediment at the bottom was dried in a microwave oven. The dry sediment samples were placed in pre-weighed plastic-cube containers and weighed and sent to S. Lund at University of Southern California for analysis.

RESULTS OF ANALYSIS FOR MAGNETIC PROPERTIES

The most exciting result of this study is a demonstration that the thin young topsoils of the batholith show an accumulation of magnetic mineral material in the upper one meter of the soil profiles (Figure 2). The weathered granite beneath the topsoil is essentially devoid of magnetic material in the fine sediment extracted in a water suspension (Figure 4). In general the topsoils are darker in color than the weathered bedrock (i.e. darker meaning having a lower value [3/ to 5/] rather than [6/ to 7/] on the Munsell Chart). The soil magnetic mineral is suspected to be maghemite, but experiments have not been done to distinguish between magnetite and maghemite. All of our bulk magnetic

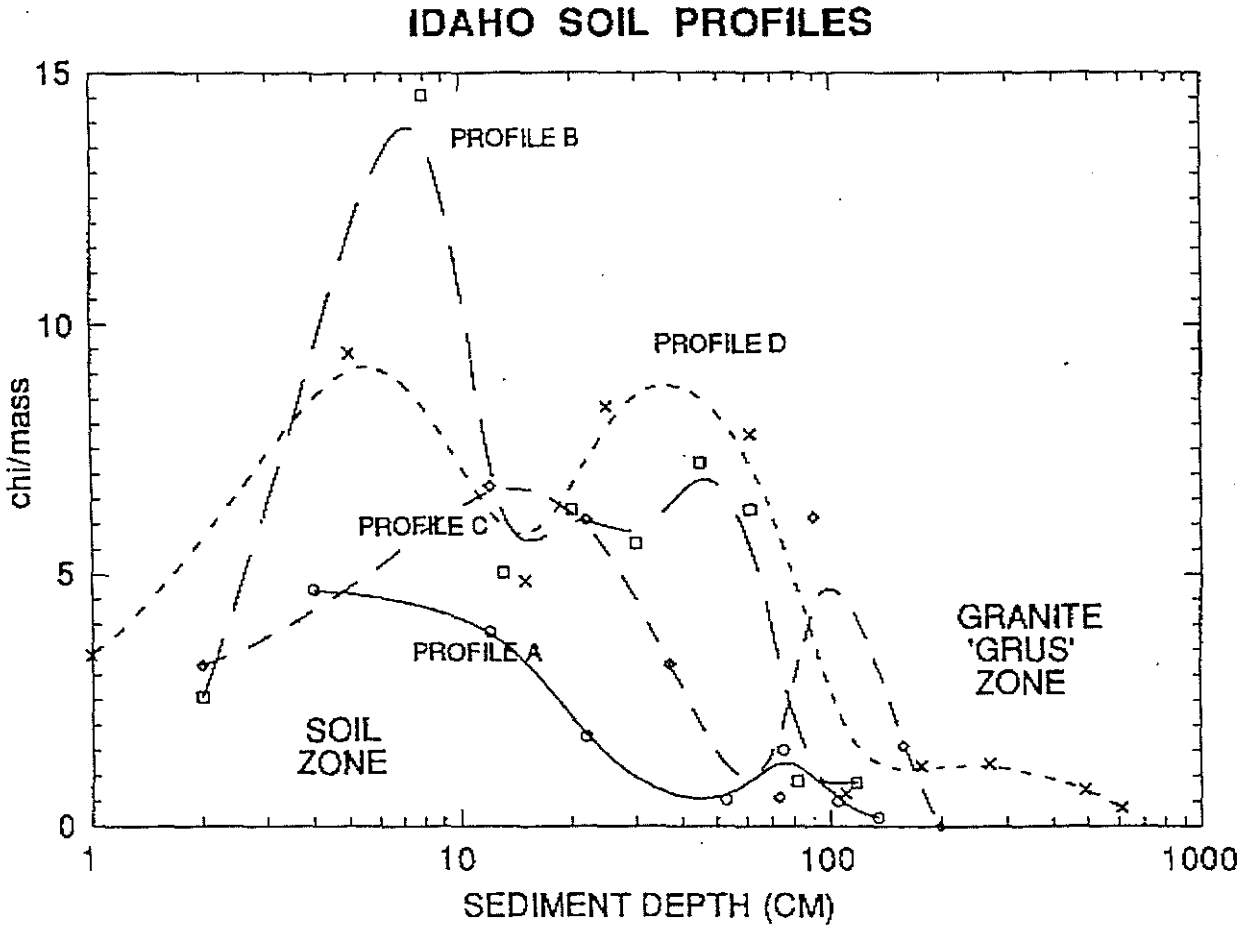


Figure 2a. Depth profiles of magnetic susceptibility (CHI/mass) for soil profiles on Idaho batholith granodiorite. Determinations were made upon fine sand and finer loose grains extracted by suspension in water) Profiles show that magnetic material accumulates in the upper 20 centimeters of soil derived from granitic rocks, but that magnetic material is essentially absent from the fines similarly extracted from the underlying weathered bedrock.

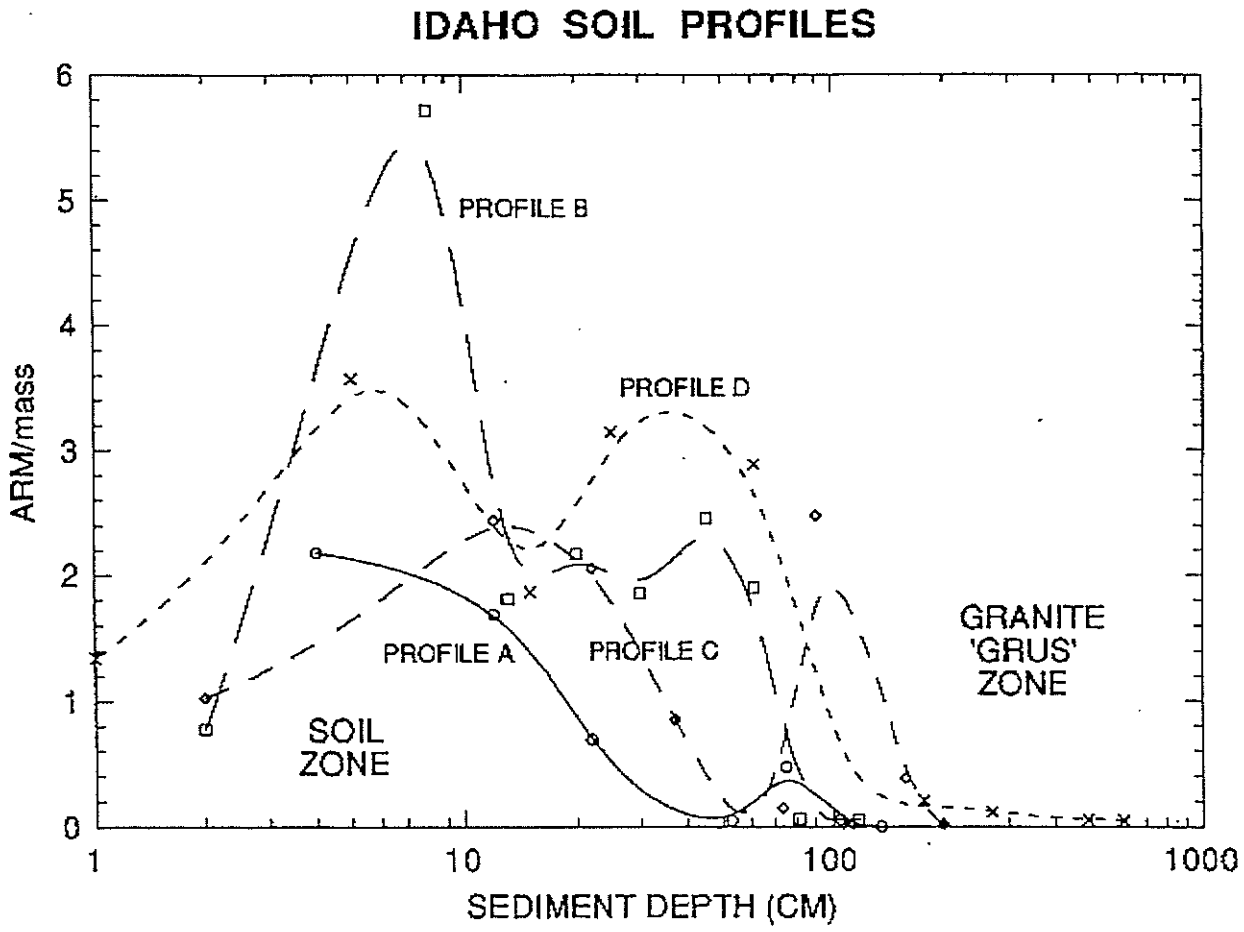


Figure 2b. Depth profile of anhysteretic remnant magnetism (ARM 0/mass) for soil profiles on Idaho batholith granodiorite.

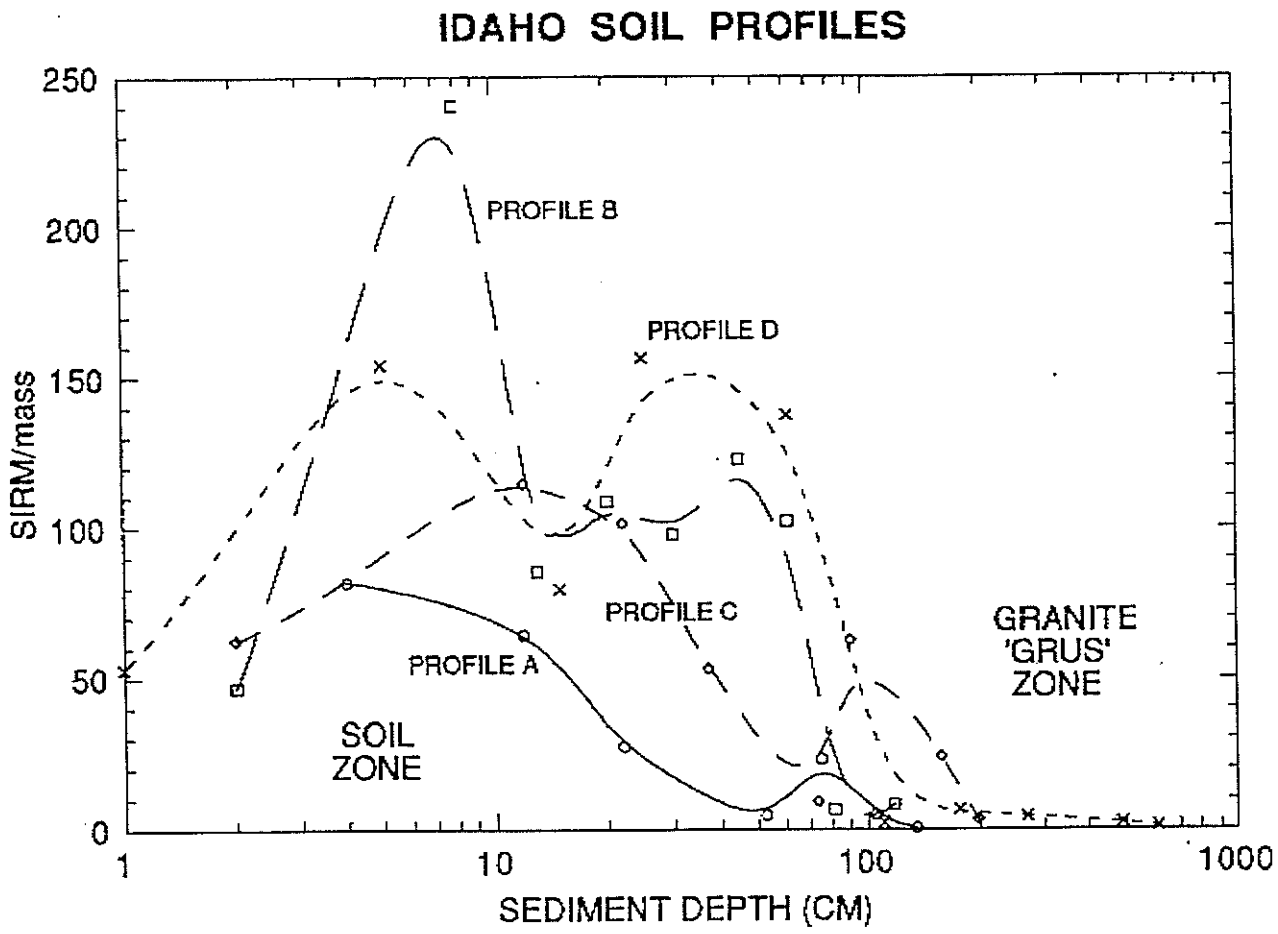


Figure 2c. Depth profiles of saturation isothermal remanant magnetization (SIRM/mass) for soil profiles on Idaho batholith granodiorite.

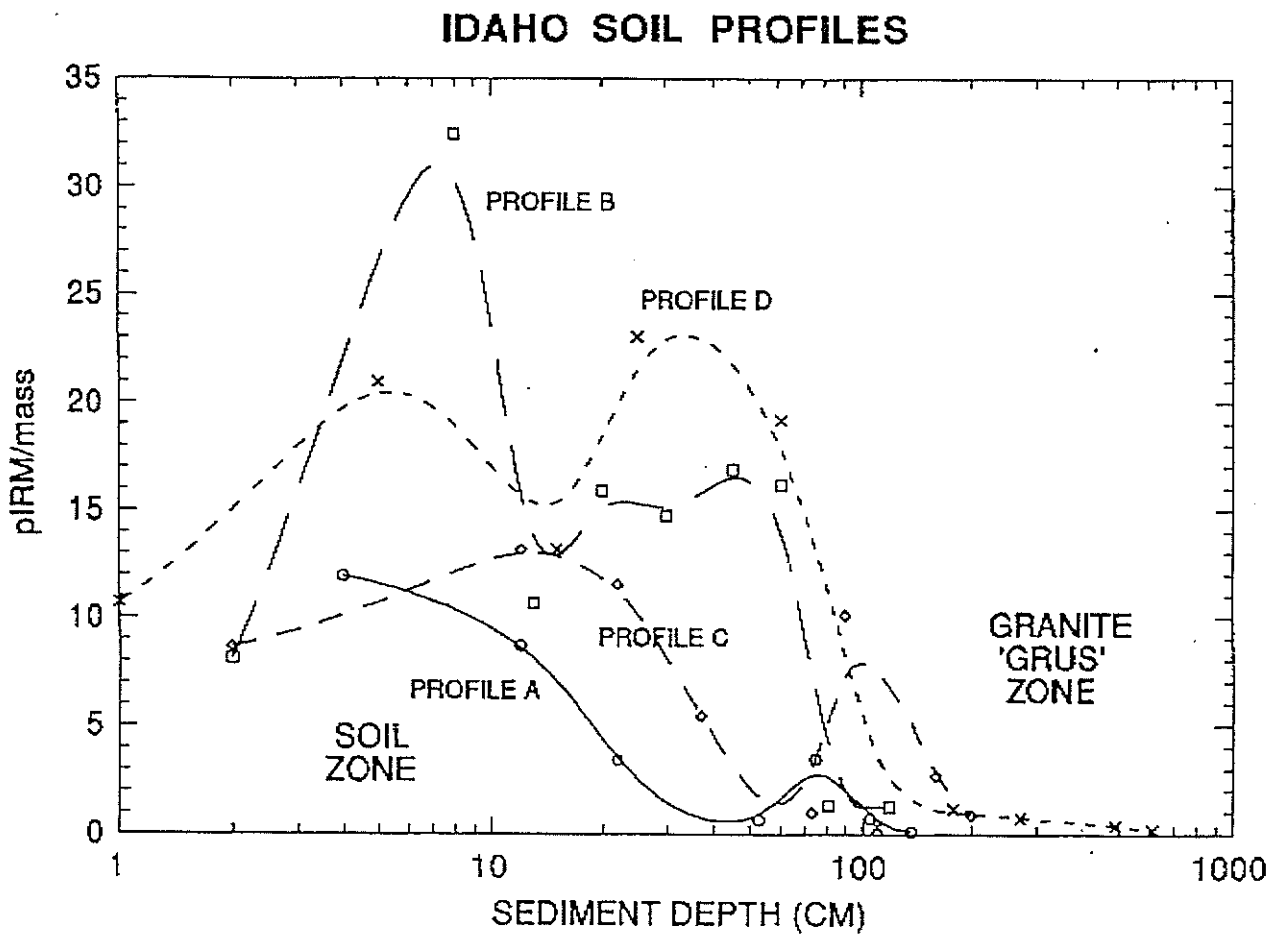


Figure 2d. Depth profiles of partial saturation isothermal remanant magnetization (pSIRM/mass) for soil profiles on Idaho batholith granodiorite.

SOIL PROFILE A

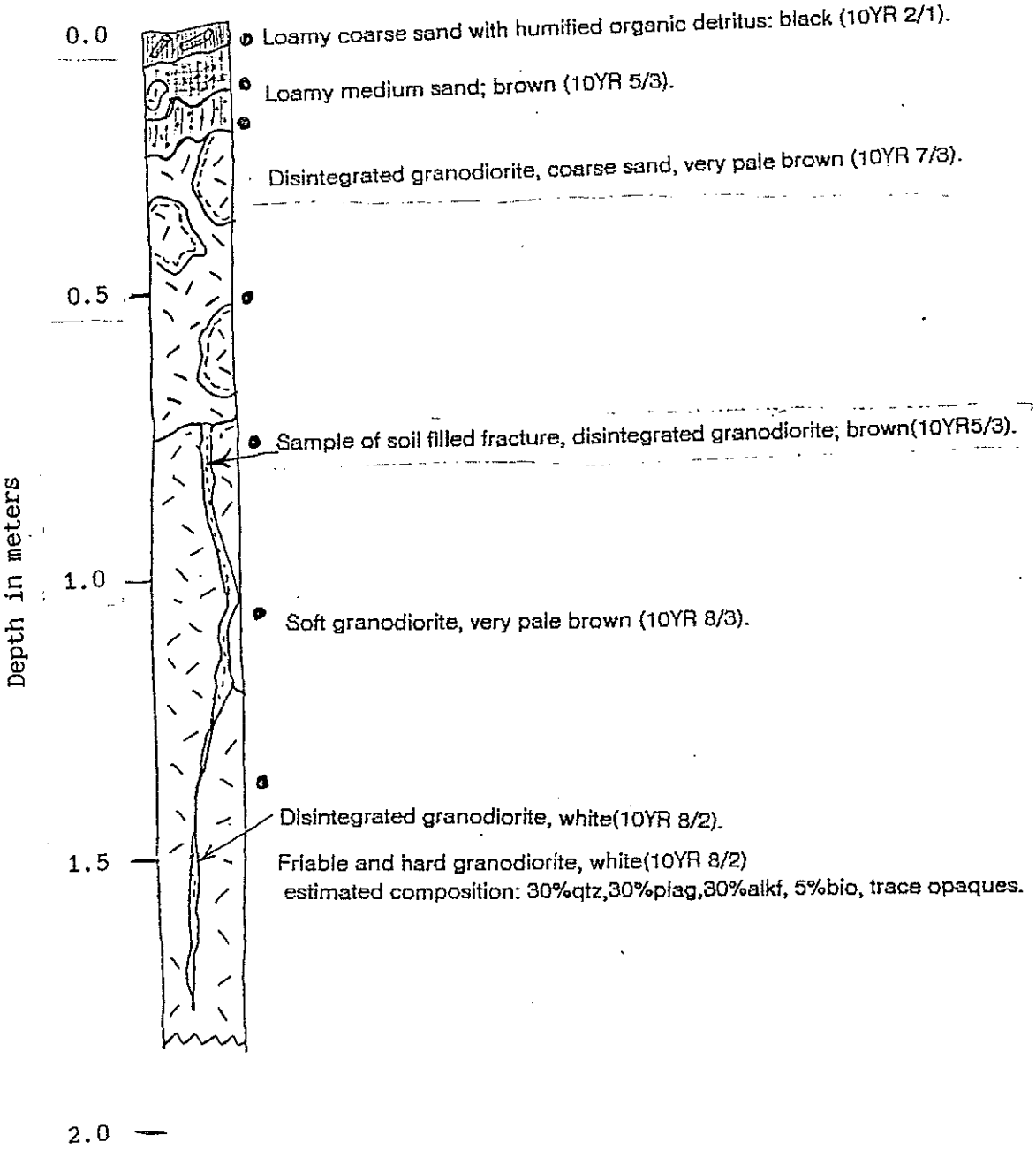

0.0
0.5
1.0
1.5
2.0
Depth in meters
Loamy coarse sand with humified organic detritus: black (10YR 2/1).
Loamy medium sand; brown (10YR 5/3).
Disintegrated granodiorite, coarse sand, very pale brown (10YR 7/3).
Sample of soil filled fracture, disintegrated granodiorite; brown(10YR5/3).
Soft granodiorite, very pale brown (10YR 8/3).
Disintegrated granodiorite, white(10YR 8/2).
Friable and hard granodiorite, white(10YR 8/2)
estimated composition: 30%qtz,30%plag,30%alkf, 5%bio, trace opaques.

Figure 3a. Soil profile A. Soil pit was dug into slope on south side of road along Silver Creek (NW1/4, SW1/4, Sec. 17). Slope is 30 degrees to northwest with coniferous forest cover and fallen logs. Bedrock samples are from an adjacent road cut. Sample points are shown by dots. Sample numbering is depth below surface in centimeters.

SOIL PROFILE B

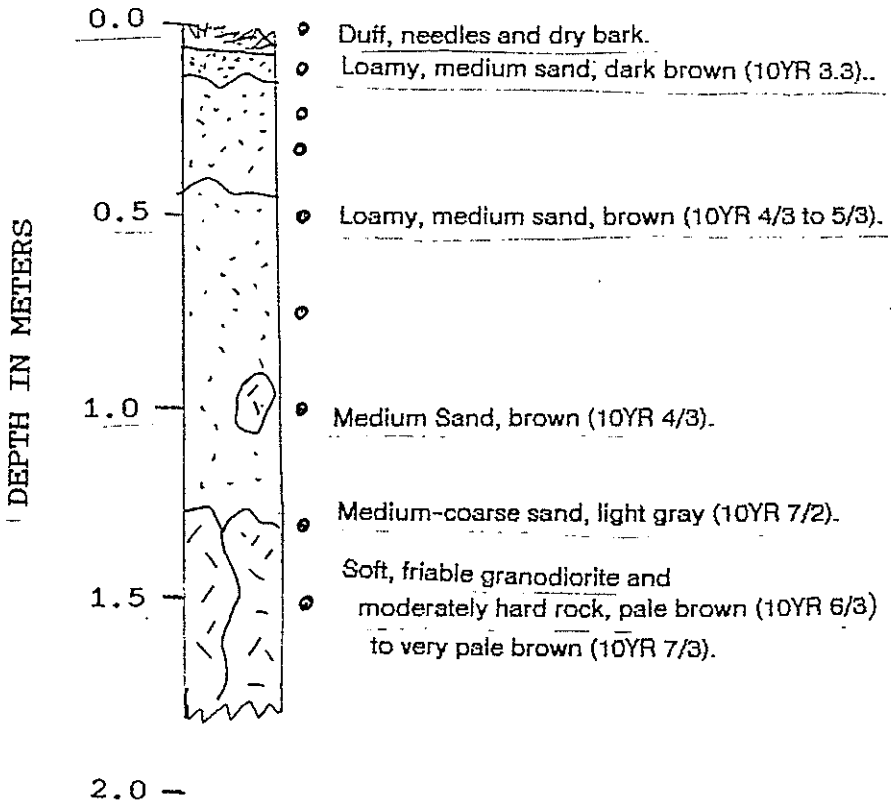

DEPTH IN METERS
0.0
0.5
1.0
1.5
2.0
Duff, needles and dry bark.
Loamy, medium sand, dark brown (10YR 3.3)..
Loamy, medium sand, brown (10YR 4/3 to 5/3).
Medium Sand, brown (10YR 4/3).
Medium-coarse sand, light gray (10YR 7/2).
Soft, friable granodiorite and
moderately hard rock, pale brown (10YR 6/3)
to very pale brown (10YR 7/3).

Figure 3b. Soil profile B. Description and samples from road cut, on a logging road spur, 100 m east from the Cabin Creek Road, SW1/4, SW1/4, Section 18, elevation 5300 feet. Slope is 25 degrees to the south. Sample points shown by dots; sample numbering is depth below surface in centimeters.

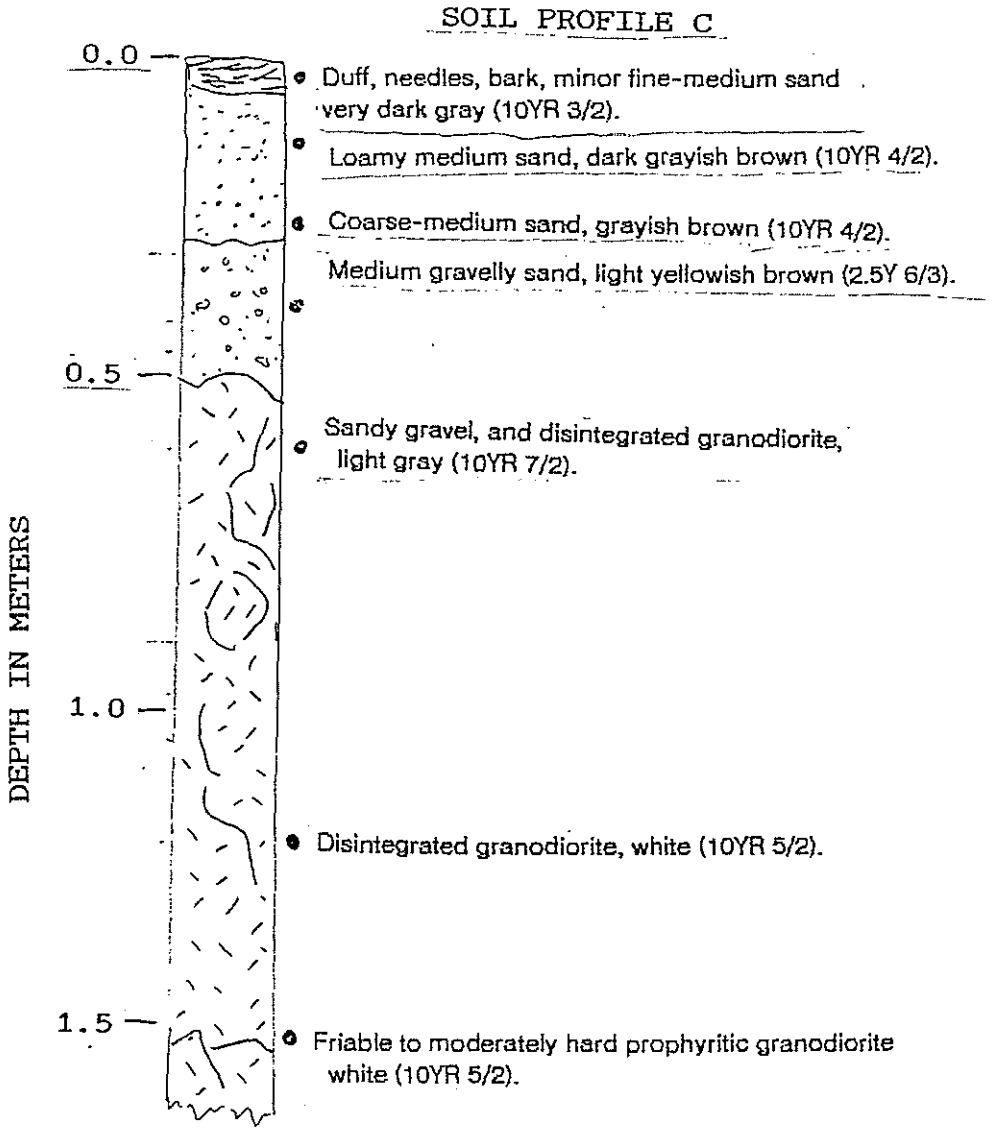

SOIL PROFILE C
0.0
0.5
1.0
1.5
DEPTH IN METERS
Duff, needles, bark, minor fine-medium sand very dark gray (10YR 3/2).
Loamy medium sand, dark grayish brown (10YR 4/2).
Coarse-medium sand, grayish brown (10YR 4/2).
Medium gravelly sand, light yellowish brown (2.5Y 6/3).
Sandy gravel, and disintegrated granodiorite, light gray (10YR 7/2).
Disintegrated granodiorite, white (10YR 5/2).
Friable to moderately hard prophyritic granodiorite white (10YR 5/2).

Figure 3c. Soil profile C. Exposed by a road cut along a spur road along a ridge crest (SW1/4, SW1/4, Section 18. Elevation 6080 feet. Site has slope of about 10 degrees to south with confiferous forest cover.

SOIL PROFILE D

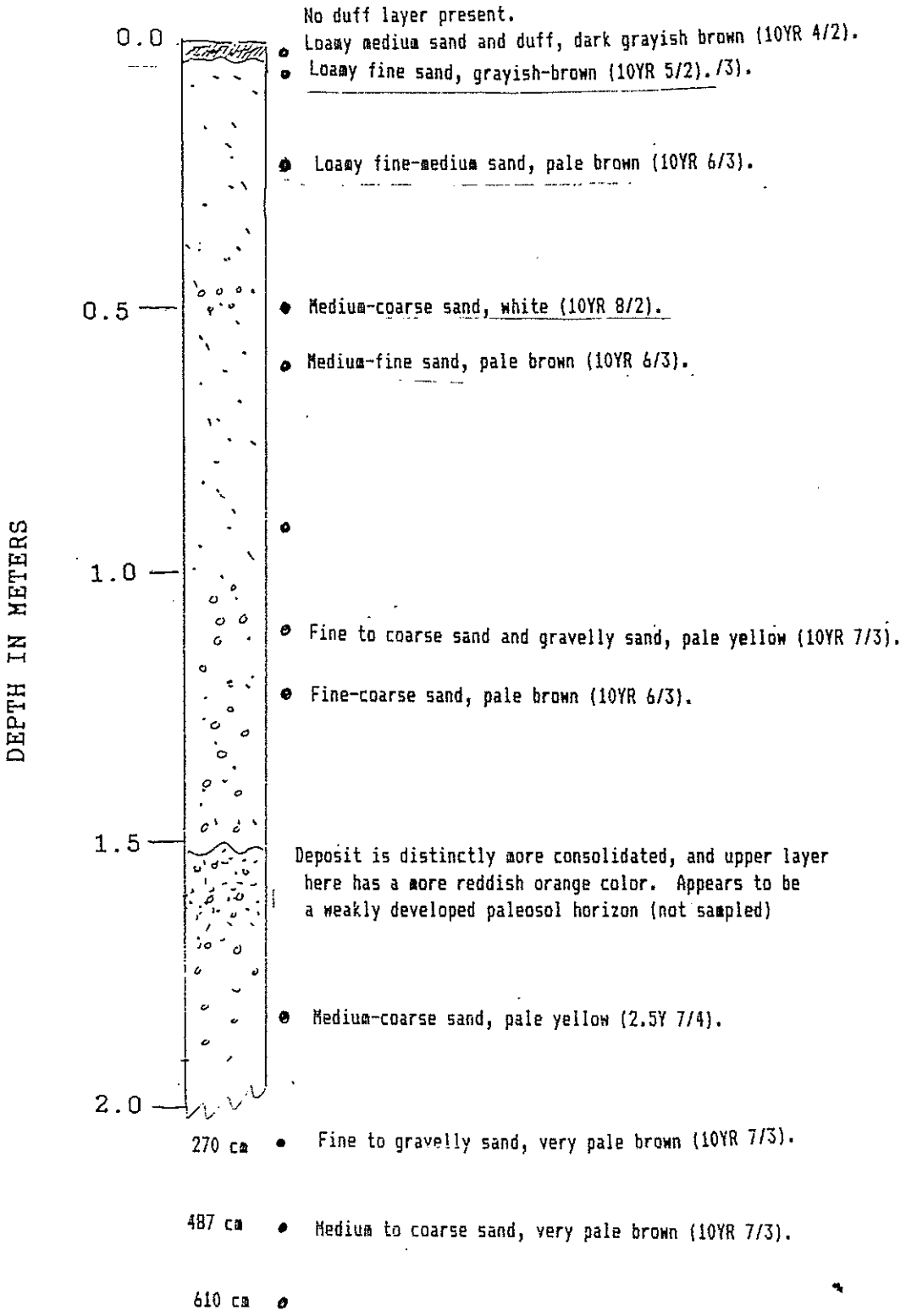

DEPTH IN METERS
0.0
0.5
1.0
1.5
2.0
No duff layer present.
Loamy medium sand and duff, dark grayish brown (10YR 4/2).
Loamy fine sand, grayish-brown (10YR 5/2)./3).
Loamy fine-medium sand, pale brown (10YR 6/3).
Medium-coarse sand, white (10YR 8/2).
Medium-fine sand, pale brown (10YR 6/3).
Fine to coarse sand and gravelly sand, pale yellow (10YR 7/3).
Fine-coarse sand, pale brown (10YR 6/3).
Deposit is distinctly more consolidated, and upper layer here has a more reddish orange color. Appears to be a weakly developed paleosol horizon (not sampled)
Medium-coarse sand, pale yellow (2.5Y 7/4).
270 cm
Fine to gravelly sand, very pale brown (10YR 7/3).
487 cm
Medium to coarse sand, very pale brown (10YR 7/3).
610 cm

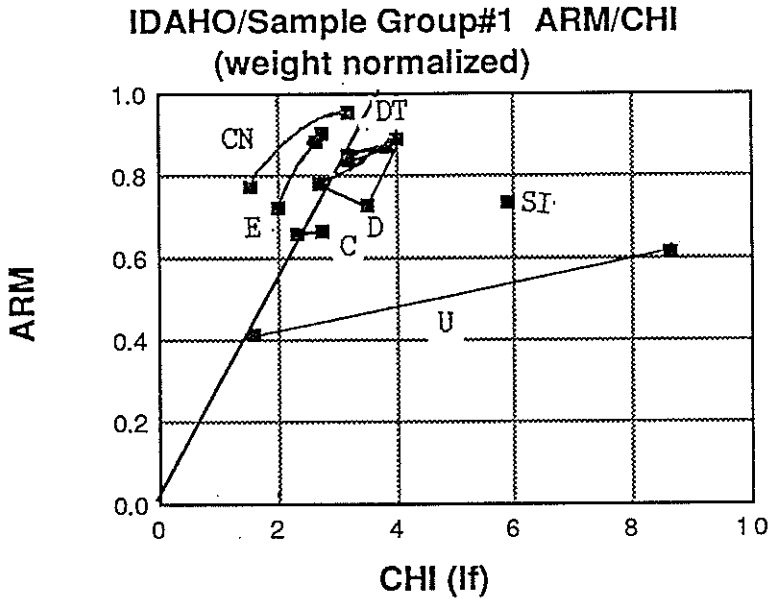
Figure 3d. Soil profile D. From a road cut on east side of Cabin Creek Road, NE1/4,NW1/4, Section 19, elevation 1683 meters (5520 feet). The road cut exposure of the soil profile is in a colluvial deposit of weathered granitic material (gruss) that is here greater than 6 meters (20 feet) thick.

mineral indicators: (magnetic susceptibility - CHI, anhysteritic remanent magnetism - ARM, and partial-saturation and saturation remanent magnetism - pSIRM and SIRM) when normalized for sample mass showed that there was essentially no magnetic material in the weathered granodiorite, and considerable magnetic material in upper meter of soil. We interpret this result to indicate that the soil formation process is making magnetic material.

In other studies the magnetic material that forms in soils has been shown to be maghemite rather than magnetite (Mullins, 1977; Thompson and Oldfield, 1986), but it is surprising to find an accumulation in apparently youthful soils of the batholith. The rock-magnetic parameter pIRM (partial SIRM) is a good indicator of very fine magnetic grains such as might be found where magnetic minerals are growing chemically. Figure 5 shows that we have high pIRM values in the shallow soils. This is consistent with the idea that all of the soil magnetic material is finely grained and is being grown in place by bacterial action associated with soil development.

Mullins (1977, p. 235) also cites forest fire as a mechanism to produce maghemite from existing magnetite or titanomagnetite. We do not know if heating by fire of existing opaque minerals in the granodiorite accounts for the relatively high magnetic properties of the shallow soil. We should also add that a significant component of loamy shallow soil may be volcanic ash, and we do not know how that would contribute to magnetism. While the authegenic formation of maghemite seems a likely mechanism for accumulation of magnetic material in the upper meter of soil, these alternative mechanisms need to be evaluated in further research.

Although all measures of material magnetism are significantly higher in the upper meter of soil, the values vary considerably. For example, the magnetic susceptibilities (CHI/mass) in shallow soils vary from 0.4 to 14, but most samples are 5 to 8 (SI units), and the 20 samples average to 5.6 ± 2.8 (1σ). The ARM/mass values in the shallow soil vary from 0.2 to 5.7, with values in the range of 1.6 to 3.5 being the most common. In the soil deeper than 1 meter and in the weathered granodiorite the CHI/mass values are all less than 1.5 and range down to 0.2. The 12 samples of subsoil average to 0.8 ± 0.5 (1σ). The ARM/mass values are less than 0.2.



SAMPLES SETTLED FROM 6-GALLON BUCKETS OF STREAM WATER

C = "C" Creek, helicopter logged, small patches
CN = Control Creek, 3 large clearcuts in 1976, no roads, burned
D = "D" Creek, helicopter, large clear cuts
DT = Ditch Creek, roads of low standards, small clearcuts
E = Eggers Creek, control watershed, no logging
U = Ucol Creek, control watershed, no logging
SI = Silver Creek just above mouth of Ucol Creek
no samples from Cabin Creek, vandals dumped buckets

Figure 4. Magnetic properties of suspended fine particles in springtime snowmelt floodwaters from creeks tributary to Silver Creek. Low-field magnetic susceptibility normalized for mass (chi/mass) is plotted against antihysterisis remnant magnetism normalized for mass (ARM/mass). CHI/mass values are 1.5 to 4.0 (SI units) with one sample each from Silver Creek and from Ucol Creek being somewhat higher. Compare with Figure 2, where CHI/mass of topsoils are in the range 1.0 to 4.0, whereas the values from gruss and weathered granite are below 0.5. This comparison supports the contention that a significant component of the suspended sediment in creeks is derived from erosion of the forest topsoil. This same data is plotted separately for each Creek in Figures 5 and 6. The figure also indicates that there is no robust difference in the magnetic properties of sediment from different creeks.

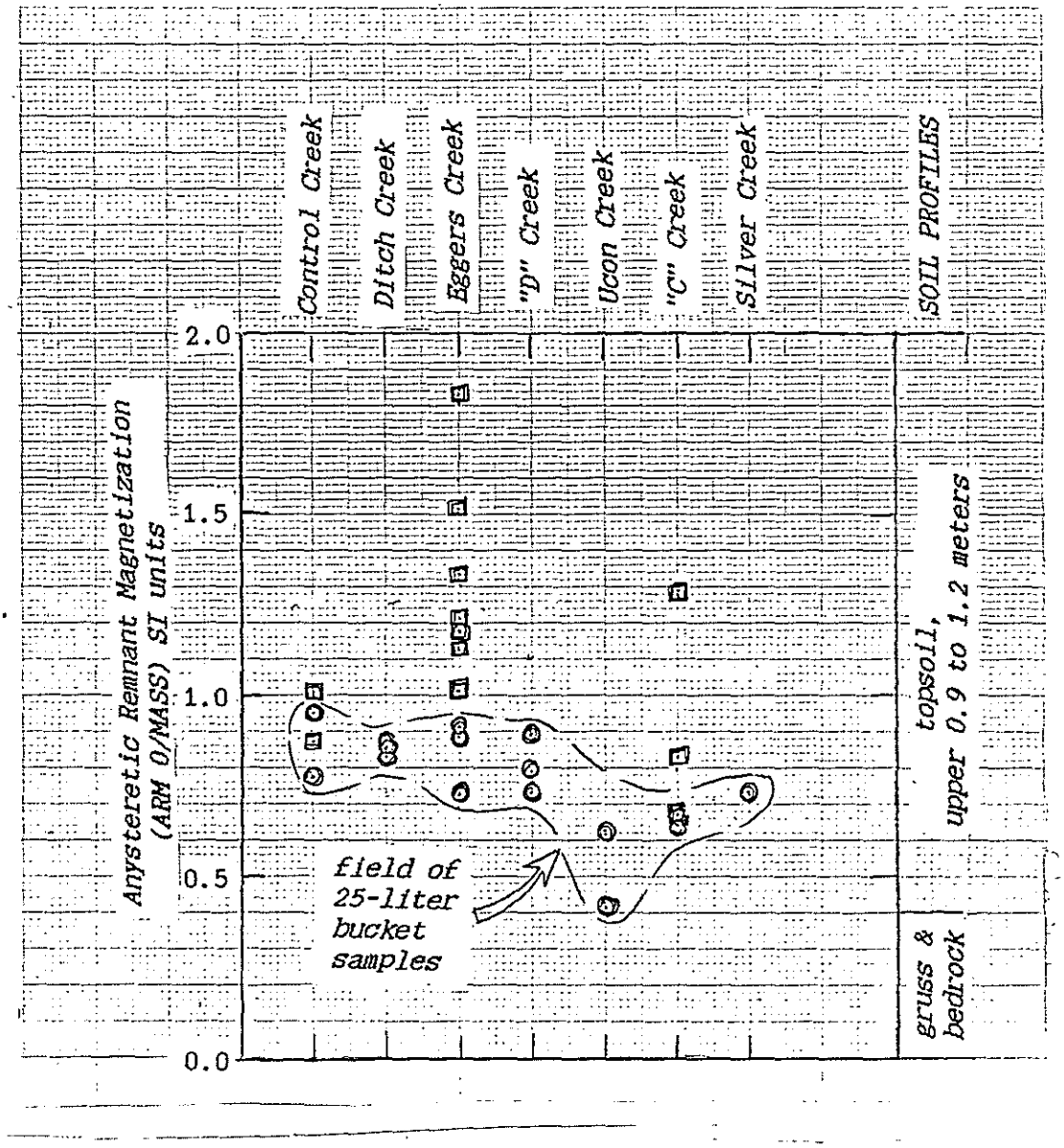


Figure 5. ARM 0/mass values for suspended sediment samples. 25-liter bucket samples shown as circled data points; 0.5 liter Manning-automatic sampler samples shown as boxed data points. Samples from all creeks were taken 13-21 April, 1989 when suspended sediment load was in the range 20 to 100 mg/liter. The wide scatter and generally higher values of ARM 0/mass of Manning-sampler points is unexplained. The implication is that those higher-value points have a greater topsoil component - but we do not know if this result is consistently reproducible for Eggers Creek - which is an undisturbed watershed.

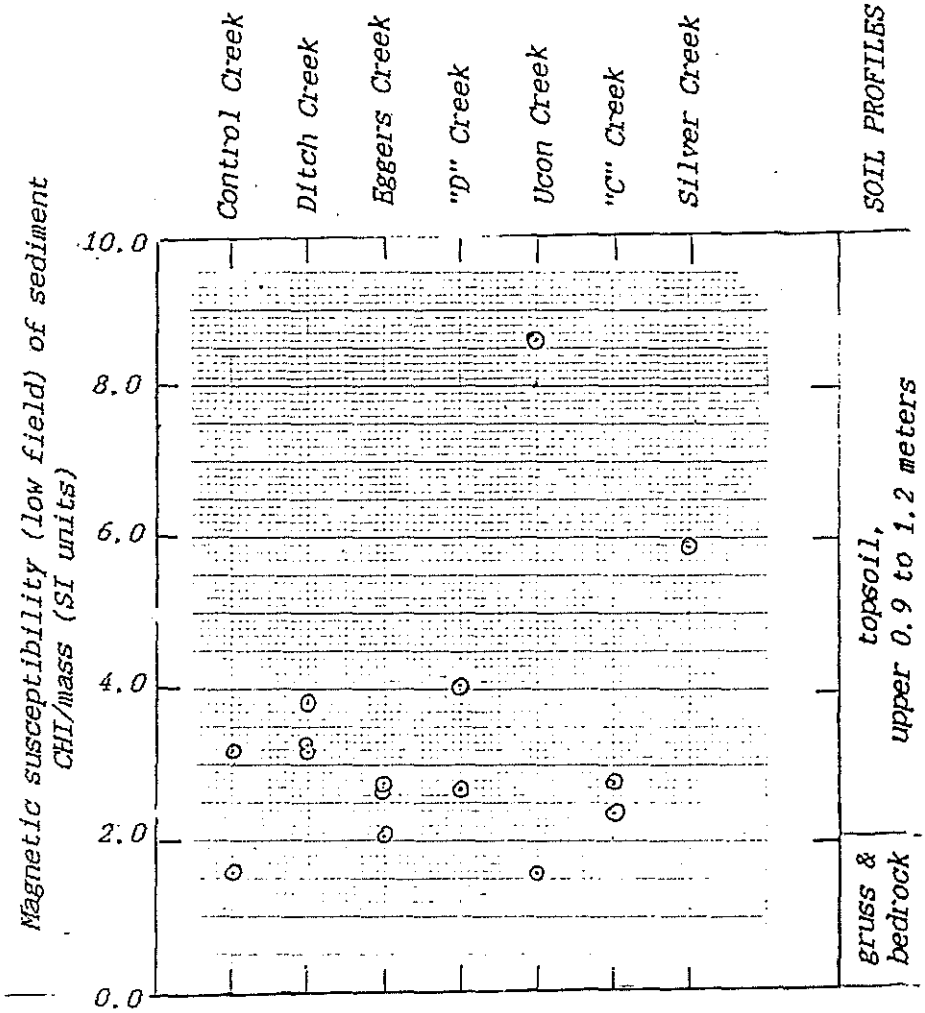


Figure 6. CHI/mass values for suspended sediment samples. These are the same samples as in Figure 5, except the Manning-sampler samples are not included as the samples were too small for susceptibility measurements.

The average value of CHI/mass for the stream sediment samples is 3.4 ± 1.8 (1σ). Since the soil average is then a crude estimate of contribution to the sediment from soil is 65 per cent, and about 35 per cent is from the non-magnetic weathered bedrock. From this we can conclude that a significant component comes from both the soil and the weathered bedrock - i.e., neither source dominates the suspended sediment in the stream.

In Figure 4 we show the ARM/mass values for stream suspended sediment - with most values in the range 0.5 to 1.0. Therefore, stream sediment samples are also lower in the amount of magnetic material than the shallow soils by this measure and also have a large component of material derived from topsoil. If we use ARM/mass of soil to average about 2.0, and weathered rock to average 0.1 and the sediment to average about 0.6, then by proportion we can crudely estimate that the soil contributes about 74 per cent of the magnetic material by mass, and it is diluted to a mass contribution of about 26 per cent weathered bedrock.

CONCLUSIONS

This study shows that magnetic mineral matter has accumulated in the upper 1.0 meter of young soils formed on granodiorite of the Idaho batholith mountains. Average low-field magnetic susceptibility (CHI/mass) of topsoil is 5.6 (SI units), whereas the average for the subsoil weathered granodiorite and colluvial deposit is 0.8 (SI units). Samples of suspended sediment from small streams during spring-snowmelt flood have an average CHI/mass value of 3.4. These values are similar to contrasts of anhysteretic remanant magnetism (ARM/mass) for soil, subsoil, and sediment and allow a crude estimate to be made of the contribution to the suspended sediment load of streams of topsoil (about 65% by mass) and subsoil weathered bedrock or colluvial deposits (about 35% by mass). Both CHI and ARM measurements are in rough agreement on the proportion of topsoil to bedrock that makes up the suspended sediment sampled in the stream waters. These calculated results only indicate the method has potential, but they should not be taken as general results until (a)a more systematic system of stream sampling is employed to understand variability of magnetic properties over the entire snowmelt cycle, and (b) samples from at least 5 more different profiles are used to verify an average topsoil value, and to substantiate reproduceability of these results.

We are intrigued that the magnetic property methods outlined in this study might be used in combination with cosmogenic-radionuclide exposure studies on sand-sized quartz grains in soils, bedrock, and stream sediments (see for example Brown and others, 1993; Repka and others, 1993) to better understand rates and mechanisms of soil formation and denudation and stream sediment transport in the Idaho batholith mountains. Magnetic property methods appear to fingerprint the soil component of the fine sand and silt fraction, whereas the cosmogenic exposure studies can fingerprint the sand fraction, and additionally provide a measure of denudation rates. Because the Silver Creek experimental watershed has an extensive data base on sediment yields and hydrology (Clayton and Megahan, 1986), such a study could produce a better fundamental understanding of forest soils and stream-transport systems of the intermountain western United States.

ACKNOWLEDGEMENTS

We thank Walter Megahan who believed that this investigation might contribute to understanding the soils and sediment transport in mountain watersheds of the batholith. Megahan served as technical advisor, S.H. Wood did the sample collection and wrote the final manuscript, and S.P. Lund made the rock-magnetism measurements and the initial interpretation of the data. Thanks to BSU students David Marks, Drew Clemens, and Mary Hegmann for help in processing the samples. The study was supported by a grant from the Intermountain Research Station, United States Forest Service, U.S. Department of Agriculture, Ogden, Utah, on a cooperative research agreement with Boise State University beginning in 1989..

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